

Analysis and Enhancements of Leader Elections algorithms in Mobile Ad Hoc Networks

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Abstract - Mobile Ad Hoc networks (MANET), distinct from traditional distributed systems, are dynamic and self-organizing networks. MANET requires a leader to coordinate and organize tasks. The challenge is to have the right election algorithm that chooses the right leader based on various factors in MANET. In this paper, we analyze four leader election algorithms used in mobile Ad Hoc Networks. Factors considered in our analysis are time complexity, message complexity, assumptions considered, fault tolerance and timing model. Our proposed enhancements include recovered nodes inquiring about the current leader and the use of candidates during election to reduce the overhead of starting a new election session. In addition, better election criteria specific to MANET, such as battery life and signal strength, are proposed. Our evaluation and discussion shows that the proposed enhancements are effective. The analysis can be used as a reference for system designers in choosing the right election algorithm for MANET.

Index Terms—Distributed Algorithms, Fault Tolerance, Leader Election, Mobile Ad Hoc Networks

I. INTRODUCTION

Distributed systems are the backbone of modern day computing services. An election algorithm elects a leader to coordinate and organize tasks in distributed systems that includes Mobile Ad Hoc networks (MANET). In contrast to traditional distributed systems, nodes arrive and leave MANET more frequently. In the case of a leader node departure or failure, nodes detecting the non-availability of the leader initiate a leader election process to select a new leader. This election process should be completed in a finite number of steps with a consensus among the nodes on the new leader [24]. Leader election is a primary control problem in both wireless and wired systems [1]. In wireless networks, leader has a variety of applications including key distribution [2], routing coordination [3], sensor coordination [4], and general control [5][6]. In this paper, we analyze four leader election algorithms applied in MANET using common factors such as time complexity, message complexity, assumptions considered, fault tolerance and timing model. Our proposed enhancements include waking up nodes that send an inquiry message to their functioning neighbors to identify the current leader instead of initiating a costly new election. In addition, we propose utilizing candidates during election to reduce the overhead, and use better election criteria specific to MANET such as battery life and mobility. Moreover, we propose to use the CSMA/CD algorithm to handle multiple diffusion computations since it requires a fewer number of messages. The organization of the paper is as follows: section II describes

the related work, and section III provides background information on leader election algorithms. The factors for our analysis are described in section IV, section V presents the

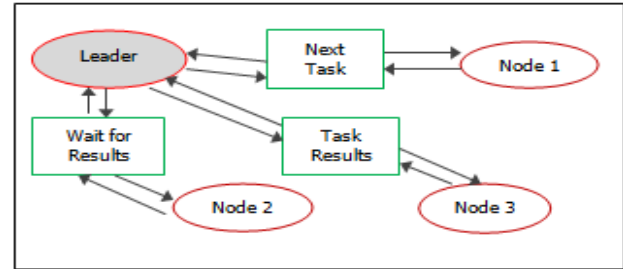


Figure 1. Typical leader coordination

analysis and the proposed enhancements, and evaluation and discussion on the analysis is presented in section VI. Finally, in section VII, we present our concluding remarks and suggestions for future work.

II. RELATED WORK

Despite leader election being a classical problem, few researchers have given importance to the leader election process in context of MANET. Leader election algorithms have different assumptions as some algorithms use synchronous message transfer [8], and others use asynchronous message transfer [7][8]. The leader election process has been studied and compared based on its complexities in [9], and the paper shows the relationship between the number of messages and the time taken for electing a leader additionally, it addresses the question of the trade-off between the time and message complexities. However, the algorithms are limited to distributed systems. A survey on Service Discovery Protocols (SDP) in MANET is presented in [10]. The survey discusses the features of several SDPs including service discovery architecture, search methods, mobility support and service description methods; however, the study is not specific to leader election algorithms. MANET's ability to continue its task uninterrupted in spite of attacks or intrusions is presented in [11]. The paper identifies the survivability properties and categorizes it into three groups: route discovery, data transmission and key management. Finally, the paper recommends that a survivable MANET needs to consider a multi-layer and multi-attack solution. However, the paper deals only with the security aspect of MANET. A survey on use of Genetic Algorithms (GA) for QoS routing in MANET is discussed in [12]. The paper does a comparative study between the two GA-based algorithms GAMAN and GLBR. The performance evaluation that was done using simulations shows that the GAMAN algorithm is a better and more

promising algorithm for QoS routing in Ad-Hoc networks. However, the survey concentrated only on the QoS routing in Ad-Hoc Networks. Mobile nodes that elect a leader within a bounded time is presented in [27]. The algorithm does not rely on the knowledge of the number of nodes in the system nor on a common start-up time. It elects a leader within a bounded time upon mobile nodes entering a specific region. However, this approach is restricted to a region and has a bounded communication diameter. An analysis of leader election algorithms in MANET is presented in [28]. The paper attempts to reduce the number of leader election processes and make the system more energy efficient. The algorithm proposes that each node should maintain a list of candidates to minimize the total number of leader elections. However, energy consumption aspect is only considered in the analysis. Most of the above work focuses on the general aspects of MANET while our work focuses on the specific leader election problem in MANET. Additionally, our analysis and enhancement provide a reference point for system designers to choose a right election algorithm in MANET.

III. BACKGROUND

A. General Leader election

Distributed systems require a coordinator/leader to coordinate and organize tasks such as implementing mutual exclusion. Leader election is required when the system is initialized, or the leader crashes. A leader election algorithm elects a leader from among the nodes considering application-specific conditions. The key to the leader election problem is attributed to G. LeLann [13]. He formalized a method to create a new token when the token is lost in a ring network. The token holder can transmit on the medium, and this token holder represents leader that coordinates tasks in distributed systems. Primary leader election algorithms are the Bully Algorithm and Invitation Algorithm [8].

B. Mobile Ad Hoc Network

MANET is an Ad Hoc network, Ad hoc is a Latin phrase meaning “for this” [14] and no topology exists among the communicating nodes that are connected [15]. MANET is highly decentralized and need a coordinator to organize their work. The coordinators are leaders of the sub-network that control routing, distributing the workload, and synchronizing the other nodes. These aspect help MANETs deal with dynamic changes simultaneously and thus MANETs are one of the best flexible networks available. Applications of MANET include wireless sensor networks, military and industrial unmanned robots, and more.

IV. FACTORS FOR ANALYSIS

We establish common factors for the analysis of the four algorithms. These factors reflect major design aspects that specify the advantages for each algorithm [16][17].

A. Complexities

Time and message complexities depend on the number of

participating nodes.

- **Time Complexity:** The number of steps required to reach consensus on the newly elected leader measures time complexity.
- **Message Complexity:** The number of messages required by nodes to elect a new leader measures message complexity.

B. Assumptions

Assumptions include all the pre-conditions required for the algorithm to work. Some algorithms assume reliable channels [18], FIFO (First in First Out) channels, or nodes that know information about their neighbors.

C. Fault Tolerance

Discussions on fault tolerance techniques are presented in [19][20][6]. Most MANET algorithms must deal with network partitioning and merging.

D. Timing Models

Timing in distributed systems is not global as there is no global clock; distributed algorithms use synchronous assumptions to achieve synchrony [18][3][21].

V. ANALYSIS AND ENHANCEMENT

A. Research of Asynchronous Leader Election Algorithm on Hierarchy Ad Hoc Network[22]

1) Analysis

Initially, the network establishes a hierarchy within election groups as shown in Fig. 2. The algorithm has two phases: the election phase and leader announcement phase. *a) Election phase:* When a node or several nodes detect the loss of a leader, each wait for a given time-out. After the time-out expires, the node sends an election message. The other node, upon the receipt of the message, forwards it to its unvisited neighbors with highest priority. Nodes that have received the election message are flagged to avoid duplicate messages. When a node has no neighbors, it will resend the election message back to sender. *b) Announcement phase:* Similar to the election phase, but in reverse order, the last unvisited node transfers the leader message, containing leader identity, to all the other nodes. Message handling is the same as in the election phase, but here the node forwards the leader message to all of its neighbors. This phase terminates when all the nodes have been visited by the leader message.

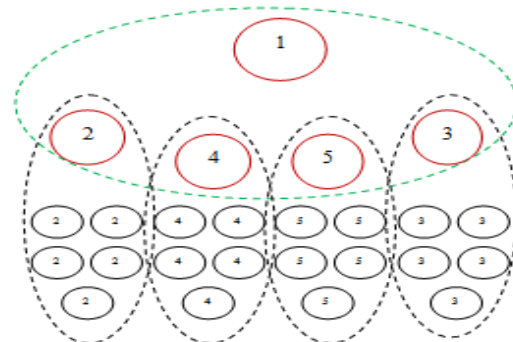


Figure 2: Hierarchy Ad Hoc Network

When a node is separated from the network during the election, it is not allowed to join the election process. However, if the node sends a 'hello' message, receiving nodes compare it with its Cluster ID and will accept or deny. The paper uses extrema finding diffusion computation and leaders are chosen considering the system's most beneficial choice. Moreover, this approach does not consider the case, in which leader node is separated during the election process. The response is to have another election.

2) Enhancements

- a) Nodes create clusters based on their locality and closeness in vicinity. Elections are conducted in tiny clusters, and then cluster's newly elected leaders broadcast their identity to other clusters similar to the approach in Garcia's Invitation Algorithm [8]. The performance is better since the initial leader election is in small groups.
- b) Un-visited nodes should not be allowed to join the election process until it is completed since this increases the overhead on election.

B. Design and Analysis of a Leader Election Algorithm for Mobile Ad Hoc Networks[1]

1) Analysis

The algorithm is based on diffusion computation and extrema finding, and it handles topological changes dynamically. When election is triggered in a node, the node starts a diffusing computation to find out its new leader. Several nodes can start diffusing computations in reply to the exit of a leader, and hence, several diffusing computations can be in progress at the same time; however, a node participates in only one diffusing computation at a time. Diffusion computation will search for a node with highest value, which is determined by the node's Unique Identity (UID). Fig 3, 4 shows a typical diffusion and shrinkage. The algorithm works in an asynchronous environment with channels that are not FIFO. When any node detects the loss of its leader, the algorithm starts. The initiator sends an 'election' message that spreads to all its neighbors thus spanning out as a tree growing. The other nodes, upon the arrival of the 'election' message, forward it to

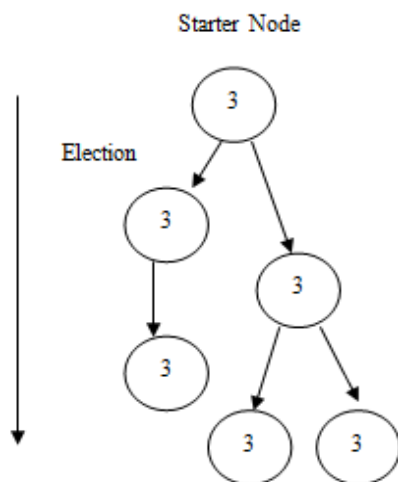


Figure 3. The diffusion of tree

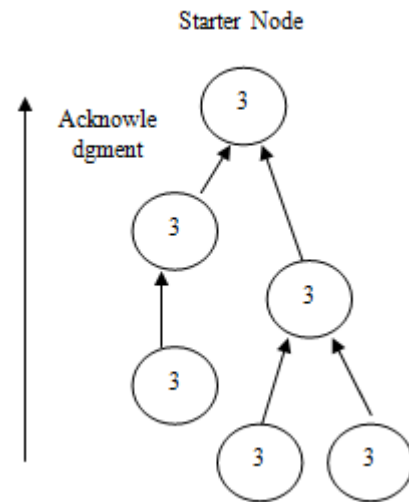


Figure 4: Spanning tree shrinkage

their children and declare the sender as their parent. When the source receives an acknowledgement, it diffuses a 'leader' message to the entire newly constructed spanning tree with the information of the current new leader.

As the number of nodes increases in the system, the 'fraction of time without a leader' increases. In addition, when considering nodes' mobility, the 'mean election rate' increases with the increase in their mobility.

2) Enhancement

- a) Algorithm assumes when a node wakes up from a crash, it should start an election to identify its new leader. This is costly. In the proposed enhancement, waking nodes send an inquiry message to their functioning neighbors and identify the current leader instead of starting a new election.
- b) The algorithm uses extrema finding using the nodes UIDs in which a node aborts its current diffusion and joins the higher order UID. A better method is to resolve the comparison based on the diffusion starter's quality as this resolves the process more rapidly.

C. A Leader Election Algorithm within Candidates on Ad Hoc Mobile Networks[23]

1) Analysis

The paper is an extension of [8] and [20]. The assumptions include nodes with UIDs, asynchronous FIFO bidirectional channels, and sufficiently large node buffers. The algorithm also deals with networks partitions and mergers that can occur during the election process. The addition to the original algorithms [8][20] is that it uses candidate lists. Candidate lists contain the UIDs of current leader and four other main candidates. When nodes confirm that the leader's heartbeats have stopped, the nodes initiate election messages. Multiple messages are handled by checking the message with the highest UID attached to it. When this election message reaches the leaf nodes in the diffusion computation-spanning tree, they send acknowledgement messages to their parents. These acknowledgment messages contain the candidate lists. On the way back to the initiator node, the lists are updated. Update is done to obtain the highest known UID of the nodes. Finally, the initiator combines the candi

date lists and the highest UID is elected as the new leader.

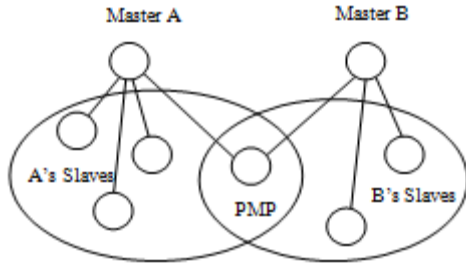


Figure 5. Participant in Multiple Piconets (PMP)

The paper derives an efficient leader election algorithm that ensures that every node has a leader in every situation and saves energy. The focus for saving energy is to reduce the number of leader election processes. Since leader election requires three phases of transmissions and receptions of messages both using a great deal of energy. The paper shows that the candidate-based algorithm saves considerable energy.

2) Enhancement

a) We recommend that election of leaders must use the highest remaining battery life and the lowest mobility range in the election process. Since nodes with low mobility have least chances of merging and partitioning from their current clusters.

b) The algorithm uses the UID to handle the multiple diffusion computations to elect a new leader. We recommend using CSMA/CD algorithm to handle such multiple diffusion computations since it requires *less number of messages*.

D. Cooperative Leader Election Algorithm for Master/Slave Mobile Ad Hoc Network[26]

1) Analysis

An election algorithm for master/slave networks is proposed in [26]. The master is responsible for assigning and coordinating tasks and roles including scheduling mutual exclusive access. The slaves follow the master's orders; the algorithm assumptions are that by utilizing the algorithm iteratively, the MANET will end up with one unique leader. The system is synchronous, and its channels are reliable. Nodes have unique IDs. In the election algorithm, each node maintains a tuple of two values, the ID of the current leader, and the current leader's master value. Nodes that wish to be the new master, replace their tuple with their own values, ID and criterion value. The master exchanges its tuple with each of its slaves. If it finds a node with higher criterion value, it will replace its own and broadcast it to the entire network of its slaves. In the network, there can be nodes that are Participant in Multiple Piconets (PMP) - a piconet is a network with at least two nodes and, at most, one master. Fig.5 shows a PMP layout. These nodes participate in multiple networks, but during each time slot, they obey only one master. When a new node joins the network and if its value is lower than the current leader of the network it just accepts the current leader. However, if the new node's value is greater than that of the current leader, the new node is the leader and the leader information is broadcast to the entire network. In case when the new node joins the network that has no leader or is yet to

establish its leader, then if its role is a master node then it increases the counter by 1 or takes no action if it is a pure slave node.

2) Enhancements

a) In the algorithm, during election only the master can communicate with the rest of the nodes. In the proposed enhancement, we recommend slave nodes be allowed to communicate during election. This reduces the election time.

b) If a node wishes to start an election process, it sends a message to its master or other active masters if in a PMP. If no master is currently active for the node, it broadcasts the need to its neighbors to start the election process, and nodes wishing to become leaders will make themselves candidates. This creates more chances for nodes to become leaders.

VI. EVALUATION AND DISCUSSION

The summary of our analysis based on Time and Message Complexity, Assumptions considered, Fault Tolerance, Timing Model, Proposed Enhancements and the Justification for Enhancements is presented in Table-I. All the algorithms consider fault tolerance, most MANET use asynchronous timing model.

A. Comparative Evaluation

a) In [1], when crashed nodes wake up, they by default start an election. Accordingly, the number of elections conducted is directly proportional to the number of nodes waking up from crash. In the proposed enhancement, nodes send inquiry messages to their neighbors to inquire about the current leader. This alternative avoids full-scale elections. For example, if we consider 5% of nodes failed, we further assume that 25% of the failed nodes contain the leader. As shown in Fig 6, the number of elections conducted is considerably less and the cost of election is minimum. In [23], when CSMA/CD is used before sending any message, the nodes wait for a certain timeout. When the ID is higher, the lower the timeout. Fig. 7 shows an scenario where node-1 fails and the message transfers. The dotted lines represent the case of using CSMA/CD and the number of messages are few.

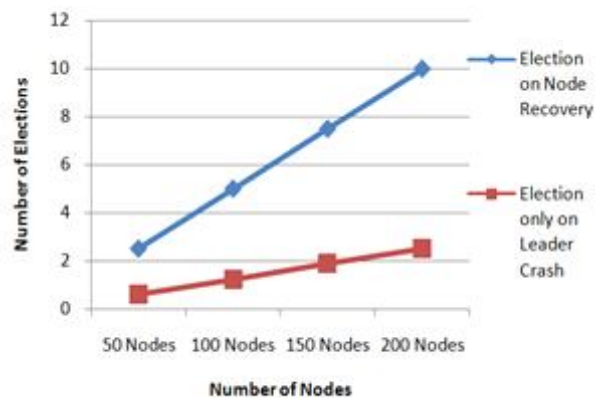


Figure 6. Number of Elections

TABLE I.
ANALYSIS SUMMARY

No	Paper	Complexity		Assumptions	Fault Tolerance	Timing Models	Enhancements	Justification for Enhancements
		Time	Message					
1	G. Zang [22]	$O(n \times (\text{average delay}))$	$O(n)$	Hierarchical networks, FIFO channels, UID	CSMA/CD for multiple elections, Handles partitions	AS	Nodes create cluster based on locality	The performance is better since the initial leader election is conducted in small groups.
							Separated nodes should not join until end of election	New nodes introduce more overhead
2	Vasudevan [1]	$O(\log ANoN \cdot PN+1^*)$	$O(PN^{**})$	Extrema finding, UID, No FIFO channels	Handles partitions, merges, and multiple elections	AS	Waking up nodes send an inquiry messages to find the leader	Re-election is costly and avoided
							Resolve based on the diffusion starter's	Rapid resolution
3	S. Lee, [23]	$O(\log ANoN \cdot PN+1^*)$	$O(PN^{**})$	Extrema finding UID, No FIFO channels	Handles partitions, merges, and multiple elections. Has candidate list	AS	Leader selection based on better traits (e.g. battery life, mobility)	Nodes with low mobility have much less chances of merging and partitioning
							Use CSMA/CD	Fewer number of messages
4	R. Ali, [26]	$\sum_{i \in P(G)} 2 \times (d(i) - P) + 1^{***}$	$\sum_{i \in P(G)} 2 \times (d(i) - P) + 1^{***}$	Reliable channels, Role aware nodes	Nodes can leave and join the networks	SY	Participation of Slave nodes	Reduction in election time
							Send invitation messages	More chances for nodes to become leaders

* ANoN is the Average Number of Neighbors in the participating nodes in the elections. PN is the Participating Nodes number.

** PN is the Participating Nodes number during the elections. SY-Synchronous AS -Asynchronous

*** P is the number of PMP nodes in the network G, P(G) is the set of PMP nodes in network G, and d(i) is degree of the PMP node i.

3) Comparisons on [1] and [22] shows, the former uses diffusion computation. This is better since the system can handle floods of messages. Moreover, when the system has more mobility, that leads nodes to leave the regions of connection and the locality of the leader. It would be better to choose [1] over [22] since the former allows multiple diffusions that may compensate the nodes' departures.

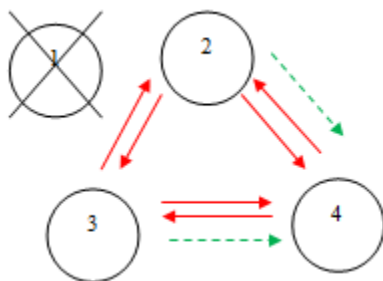


Figure 7. CSMA/CD in Leader election

4) Comparisons on [25] and [26] show that both use extrema finding, yet the latter uses a valued node property in order to evaluate candidate nodes for leadership. Also, in the latter the master can only exchange messages with the slave nodes while the former allows nodes to flood messages forming trees rooted at the initiator node. Finally, a major difference in

[26], is that it is a synchronous algorithm while the rest are asynchronous.

B. Evaluation based on Factors

1) Complexities

The time and message complexities of all the algorithms presented in Table-I show they are linear. All algorithms are efficient; they only differ in the number of participating nodes or delay.

2) Fault Tolerance

Most algorithms handle partitions and merges. The use of FIFO channels is also present. In [23], candidates are used to avoid consecutive elections. We recommend using candidates in algorithms, since this reduces the overhead of starting a new election session.

3) Assumptions

Assumptions limit the algorithm from its wide applications, hence minimum the assumptions lead to the greater adaption of the algorithm in real applications.

4) Timing Models

Most MANET use asynchronous timing model. Nodes have no global time coordination among them.

VII. CONCLUSION AND FUTURE WORK

We presented an analysis on leader election algorithm in MANET. Factors considered in our analysis are time complexity, message complexity, assumptions considered, fault tolerance and timing model. The analysis results showed all algorithms analyzed considered fault tolerance in-depth. Our proposed enhancements include on recovery, nodes inquire about the current leader instead of initiating a new election process. In addition, we propose utilizing candidates during election to reduce the overhead, and use better election criteria specific to MANET such as battery life and mobility, using an asynchronous timing model is a better choice as most MANET are asynchronous. Moreover, we propose to use the CSMA/CD algorithm to handle multiple diffusion computations since it requires fewer number of messages. As a part of future work, we intend to include more recent leader election algorithms, additional factors for our further analysis, and empirical studies on proposed enhancements in the paper.

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